In addition to the previous observations, it is important to note that if nothing is done differently, the U.S. Government will spend $233B for space launch through 2030 for the assumed mission model of section 2. Option 1 only reduces that total by $3B over 35 years. Option 2 reduces the life-cycle cost by $41B in non-discounted dollars, or 17.6 percent. Option 3A reduces the life-cycle cost by $35B, or 15 percent. Option 3B reduces the life-cycle cost by $64B, or 27.5 percent.

Thus, the life-cycle cost savings for Option 3B are the greatest of all of the options, averaging a savings of $1.8B per year over the 35 year period through 2030.

		Current Program	Option 1 (Retrofit + ELV Fleet)	Option 2 (Lg. + Sm. Veh. + Delta)	Option 3 (SSTO-R, 30-ft Bay + Titan)	Option 3 (SSTO-R, 45-ft Bay)
Costs	Technology	0	Incl. in DDT&E	$0.4B	$0.9B	$0.9B
	DDT&E (Incl. Technology)	0	$2.4B	$11.1B	$17.6B	$18B
	Production	0	$5.6B	$2.0B	$18.1B	$18.7B
	Operations (Out-Years)	$6.4B/yr	$6.1B/yr	$4.0B/yr	$2.6B/yr	$1.4B/yr
	Life-Cycle Costs	$233B	$230B	$192B	$198B	$169B
Operations Cost Metrics**	Average $/Launch (Shuttle Replacement)	$322M (STS)*	$293M (STS)*	$85M (Sm.) $205M (Lg.)	$41M	$38M
	$/lb of Payload (Fleet Average for Mission Model)	$7,488/lb	$6,814/lb	$6,100/lb	$3,900/lb	$2,100/lb
	$/lb of Payload (Full Veh., to LEO, 28°)	$6,850/lb (STS)*	$6,234/lb (STS)*	$3,900/lb (Sm.) $1,600/lb (Lg.)	$980/lb	$920/lb
	$/lb of Payload (to the Space Station)	$12,880/lb	$11,720/lb	$3,700/lb (Lg.)	$1,600/lb	$1,500/lb

* Current Space Shuttle capability (no ASRM)

** In the out-years

• Constant FY94 dollars; no "new ways of doing business."

FIGURE 39.—Summary of option costs.

Referring to the cost metrics portion of the figure 39, it is shown that the fleet-average launch costs for the mission model were reduced from the current values of $7,488 per pound to $6,814 per pound for Option 1; $6,100 per pound for Option 2; $3,900 per pound for Option 3A, and to $2,100 per pound for Option 3B. The lowest cost per pound of payload for the new vehicles launching into a 28-degree inclination low orbit were $920 and $980 per pound for the two Option 3 cases. Next higher were the $1,600 per pound to $3,900 per pound for the two different sized vehicles in Option 2, with the commercially significant smaller vehicle having the larger cost per pound. The cost for Option 1 was $6,234 per pound.

The Space Shuttle costs per launch were calculated consistent with the methodology historically presented to OMB and GAO. While all the costs were lower than the $6,850 to $7,488 per pound for the current Shuttle program when computed the same way, it is clear that the major cost savings targeted as a goal for this study only accrue in architectures employing new vehicles. In addition, it is also clear that Option 3 lowers the launch costs by the largest amount.

The cost per launch to a Space Station in a 220 nautical mile circular, 51-degree orbit showed similar trends, the lowest being $38 to $41M for Options 3A and 3B, $85 to $205M for the Option 2 vehicles, and $293M per launch for the Space Shuttle, computed in the same way. The cost per pound of payload to the new Space Station orbit also showed similar trends.

It is possible that the above operations cost metrics might be reduced further by adopting the so-called new ways of doing business, but the savings obtained may be less than the 30 to 40 percent predicted for the design, development, test, and evaluation, and production reduction. This is because the operations costs are already based on streamlined operations concepts, at least for Options 2 and 3. In addition, further reductions may be possible by buying launch services from the private sector, but the effects have not been well quantified.

It is clear from examination of the cost results that large annual cost savings are possible, but they can only be attained by considerable up-front investment—the larger the investment, the larger the operations cost savings. It is also clear that the attainment of costs substantially below about $900 per pound of payload into a 28 degree low-Earth orbit requires further understanding of the savings obtainable with new ways of doing business, larger mission models requiring more frequent flights, technology beyond that of any alternatives considered in this study, or, most likely, a combination of all these factors.

Other Assessment Factors

Eight major factors were assessed, including a summary of the costs from the previous figure. These assessment factors are displayed in the matrix of figure40.

	Option 1 Shuttle Retrofit	Option 2 Architecture 2D (Lg. + Sm. + Delta)	Option 3 SSTO Rocket + Titan	Option 3 SSTO Rocket
National Launch Needs	Meets Model	Meets Model Except 125k lb/yr Downmass (Provides 25k lb)	Meets Model	Meets Model (If DOD P/L Shortened)
Vehicle Reliability	Meets 0.98 Goal for Shuttle and Delta	Meets 0.98 Goal for New Vehicles and Delta	Meets 0.98 Goal for New Vehicle	Meets 0.98 Goal
Crew Safety	Does Not Recommend Significant Improvement	Meets 0.999 Goal	Meets 0.999 Goal	Meets 0.999 Goal
Summary Costs	Does Not Approach 50 Percent Reduction Goal	Approaches 50 Percent Reduction Goal	Exceeds 50 Percent Reduction Goal	Far Exceeds 50 Percent Reduction Goal
Operability	Significant Shuttle Improvement. ELV Fleet As Is	New Vehicles:Robust and Highly Operable. Delta, Pegasus As Is	New Vehicles:Robust and Highly Operable. Titan As Is	New Vehicles:Robust and Highly Operable.
Technical Risk	Low	New Vehicle—Low; HL-42—Moderate	Moderate-to-High	Moderate-to-High (More Technology Required)
Cost Risk	Low-to-Moderate	Moderate	Moderate-to-High	Moderate-to-High
Other Factors	Additional Orbital Capabilities	Achieves Parity With International Competitors	Major Increase in International Competitiveness	Major Increase in International Competitiveness

FIGURE 40.—Option comparison.

National Launch Needs

All the options met the requirement to launch the mission model of the Purpose section. The requirement also existed to return all of the mass taken to the Space Station, which was met by Options 1 and 3, but not by Option 2, which returned only approximately 20 percent. This was a feature of the down-selected architecture, and was adopted in order to minimize new vehicle and carrier sizes and costs. The cost of the expended Space Station carriers and racks resulting from this limitation were accounted for in the operations cost analysis.

An additional factor applied to Option 3B, which was able to launch the longest DOD payloads only if the DOD downsized them to 45-feet in length. Preliminary discussions with the DOD indicated that such downsizing was a distinct possibility at the time the payloads were due for a block change, about 2002. Indeed, there has already been some Congressional language urging the DOD in this direction in order to allow retirement of the expensive Titan vehicles. Thus, while the possibility of having shorter payloads might be realistic, nonetheless, the viability of Option 3B rests on this assumption.

Vehicle Reliability

All vehicles except the Atlas and Titan met the goal of having a vehicle reliability greater than 0.98 percent. It was felt that it was unlikely that these two expendable launch vehicles could be upgraded to that reliability in a cost-effective way, while the Delta is almost at this reliability level already. All the new vehicles were designed to exceed this requirement.

Crew Safety

The improvement of crew safety (probability of crew survival) to at least 0.999 from the 0.98 of the Space Shuttle was met or exceeded by the new vehicles of Options 2 and 3. Option 2 had a launch escape propulsion system for the entire crew carrier, while Option 3 adopted escape seats and intact abort of the vehicle into orbit or return to the launch site.

Option 1 did not recommend the addition of escape seats, an escape pod, or liquid boosters to the Shuttle and, thus, did not improve significantly on the current crew safety analysis. The reason for this recommendation was that the analysis showed that the expense for incorporation of additional escape capabilities was high, and that there was a significant impact on current vehicle capabilities due to factors such as a major shift in the orbiter center of gravity.

Summary Costs

The costs discussed with reference to figure 39 indicate that Option 1 did not approach the 50 percent cost savings goal; Option 2 approached it, though it did not meet the goal, reducing operations costs by about 37 percent; and both Option 3 alternatives exceeded that goal—Option 3A reducing costs by 59 percent and Option 3B by 78 percent.

A number of observations were made regarding relative costs. One was the difficulty of reconciling cost estimates for operational systems, which are well understood, with those for new vehicles whose definition is still in the pre-PhaseA state.

Compounding that difficulty was an uncertainty in the amount of cost growth margin to include in the estimates, which, in existing systems, was felt to be largely governed by external factors rather than inherent growth due to inadequate definition or design errors. The teams questioned, therefore, whether the historical cost growth allowances using conventional NASA models are too conservative if new management schemes are to be adopted that might better be able to shield the program from external factors.

An additional observation is that the NASA cost models are designed to predict development costs and lack a rigorous process for predicting operations costs. Nevertheless, the estimates developed for the Access to Space Study were made with guidance from experienced costing teams using the best costing tools available.

Operability

Enhancements in the operability of the three options were also assessed. Option 1 improved the Shuttle operability somewhat, but that of the companion expendable launch vehicles was unchanged. Thus, taken as a whole, the operability of Option 1 was not significantly improved over the present situation.

All the new vehicles of Options 2 and 3 had designs, infrastructure, and operations concepts specifically tailored for operability and robustness, and associated significant reductions in operations costs. However, Option 2 retained the Delta and Option 3A retained the Titan, and, thus, their overall operabilities were thus somewhat degraded. Therefore, Option 3B promised the best operability of the three options.

Technical Risk

It is apparent that the technical risk will increase with adoption of new design vehicles, and even more so if new technology is utilized. Thus, the technical risks were assessed as low for Option 1, low for the new vehicles of Option 2 since their designs have been defined in detail under the Advanced Launch System and National Launch Systems programs, moderate for the HL–42 crew carrier vehicle of Option 2, and moderate to high for Option 3 due to the incorporation of new technology. Even though Option 3 incorporates new technology, its risk was felt to be manageable due to the 4 to 5 year technology maturation phase which would develop and demonstrate the needed technologies to at least a level 6 technology readiness level (proven in their operating environment).

Cost Risk

The cost risk was principally due to the schedule impacts of technical uncertainties during development. It was felt to be low to moderate for Option 1, moderate for Option 2, and moderate to high for Options 3A and 3B, the latter driven largely by the presence of new developments and new technology.

There was also a recognition that while the options that had new vehicles incurred greater cost and schedule risk, this risk increased in proportion to the cost savings they would enable.

Other Factors

In addition to the factors assessed above, there are a number of other distinguishing features of the options that should be considered in making an architectural selection.

The first of these is the total capability of the Space Shuttle which, in addition to providing launch and return of payloads, has a capability to capture and repair spacecraft, and is also a crewed orbital research and development facility with an orbital flight duration of at least 2 weeks. These capabilities would not be replicated if Options 2 or 3 were to be selected, as crewed orbital laboratory functions are to be assumed by the Space Station. However, if the Space Station is not available, for whatever reason, this factor could have an overriding importance.

Another such factor is the ability for the U.S. commercial launch industry to compete in the international satellite launch market. Option 1 does nothing to improve the current situation. Option 2 would achieve approximate parity with the projected prices of the Ariane IV and Ariane V, the most efficient of the foreign systems, only after a lengthy development period. Option 3, on the other hand, would lower launch costs so dramatically that U.S. industry could underprice all competitors. The U.S. would likely capture, and once again dominate, the international satellite launch market for a considerable period of time, utilizing these unique advanced technology vehicles.

Lastly, it was recognized that providing two different means for assured access to space for every important payload will be prohibitively expensive, no matter how desirable. One way out of this dilemma is to recognize that the world has changed and that the international space launch community now has the capability and reliability to function as a backup, for launching U.S. payloads in the case of extensive groundings of U.S. launch vehicles. Thus, while some payloads would have to be designed to be compatible with more than one launch vehicle, assured access to space may be attained by any of the options studied, without major additional investment, by proper agreements with other nations.

Observations and Conclusions

Assessment of the characteristics, performance, and costs of the architectures recommended by the option teams led to a number of observations which, in turn, lead to the study conclusions. These are presented below.

Cost Reductions and Safety Increases

The study determined that it is indeed possible to achieve the objectives of large reductions of operations costs and increases in reliability and crew safety at the same time in the same architecture. It did not appear that reasonable modifications to the Space Shuttle could achieve these objectives in a cost-effective manner, though a number of beneficial improvements to the Shuttle system were identified.

New vehicles were required in the architectures to attain these objectives. These vehicles could be constructed using either conventional or advanced technologies, with the conventional technology vehicles approaching the 50 percent desired minimum operations cost reduction (37 percent reduction), and the advanced technology vehicles greatly exceeding it (up to 78 percent operations cost reduction).

Design, Development, Test, and Evaluation Budget

Both current technology and new technology vehicles achieved the targeted operating cost reductions only after sizable design, development, test, and evaluation budget investments. This budget investment was smaller, but immediate, for the Option 2 architecture using current technology new launch vehicles and carriers. Both of the Option 3 architectures required a larger design, development, test, and evaluation budget, but start of their development was delayed 4 to 5 years as a result of the necessity of maturing and demonstrating the required technologies. Thus, Option 3 is more consistent with projected near-term budget availability.

Annual Operations Costs

The annual operations costs of the Option 3B architecture were the lowest of all, since the new vehicle replaced all the current generation launch vehicles which have large operations costs.

The achievement of these low operating costs was completely dependent on making large-scale changes in the way vehicles are designed, developed, managed, contracted for, and operated. It was concluded that associated designs must all be driven by operations, as well as by performance, and that resulting architectures must also entail the major changes in launch infrastructure and operations "culture" referred to as "new ways of doing business."

Most Attractive Option

In view of the above, an architecture featuring a new advanced technology single-stage-to-orbit pure-rocket launch vehicle was recommended as the most attractive option. It has the greatest potential for reducing annual operations costs as well as life-cycle costs, it would develop important new technologies with dual-use in industry (such as composite vehicle structures for cars and airplanes), it would place the U.S. in an extremely advantageous position with respect to international competition, and would leapfrog the U.S. into a next-generation launch capability.

The preferred single-stage-to-orbit rocket alternative is that in which the vehicle is sized so as to accommodate all payloads in the mission model, so as to avoid the need to carry current Titan expendable launch vehicles in parallel. The lowest operations costs resulted from selecting this single-stage-to-orbit pure-rocket vehicle as the focal point of the new launch architecture.

The large development costs associated with this new vehicle would be put off for at least 5 years while the technology was being matured and demonstrated. This would allow at least that time period for measured consideration of the decision to start a new vehicle program.

On the other hand, delaying the decision of which vehicle architecture to select by 4 or 5 years but not funding a focused technology phase will achieve nothing, since the lack of a focused technology program during that period will not reduce the risks of developing an advanced technology vehicle. Therefore, the choices available in 4 to 5 years would be exactly the same as those we face today.

Technology Maturation and Demonstration

The assessment that the best option is to develop a new, fully reusable, advanced technology single-stage-to-orbit rocket launch vehicle is absolutely dependent on maturing and demonstrating the required technologies before initiating development.

Though it is possible to start development right away and perform technology maturation and demonstration concurrently, such an approach carries with it greater technical, schedule, and cost risks. Further, it would immediately require large budgets, precluding the 4 to 5 years of relatively modest budgetary investment. However, once the required technologies are matured and demonstrated at the subsystem/system level in the pertinent environment, the perceived risk is much reduced and should be manageable.

The technologies that require maturation and demonstration include graphite-composite reusable primary structures, aluminum-lithium and graphite-composite reusable cryogenic propellant tanks, tripropellant or lox-hydrogen engines designed for robustness and operability, low-maintenance intergral or standoff thermal protection systems, autonomous flight control, vehicle health monitoring, and a number of operations-enhancing technologies.

These technologies must be demonstrated on the ground and through flights of an experimental rocket vehicle. Technologies that interact should be tested together, both on the ground and in the experimental vehicle. A second objective of an experimental vehicle would be to validate the vehicle design models that are used to predict the characteristics and performance of single-stage-to-orbit rocket vehicles.

Technology Applicability

The current expendable launch vehicles and the Space Shuttle will have to be operated for at least another 10 to15 years before new launch vehicles can be available. Improvements to the fleet vehicles that significantly improve their operability and possibly reduce their operating cost should continue to be considered for implementation.

The technology program for the single-stage-to-orbit rocket would result in the evolution of numerous capabilities and/or components/subsystems that could be directly applied to these current launch vehicle systems. These could improve the operability and, to some degree, the cost performance of the current generation expendable launch vehicle fleet and the Space Shuttle until such time as the new vehicles became available to be phased in. The decision to upgrade the current fleet can be incremental and independent from that to start the technology program.

The new technologies will generally support the development of any type of new generation launch vehicle, even if initiated further in the future. In addition, most of these technologies are highly beneficial in their own right for applications throughout the civilian and defense communities and the commercial marketplace.

Space Shuttle

Even though improvements to the Space Shuttle were identified and new vehicle designs were conceived that potentially could improve its cost and safety, it was clear that the Space Shuttle remains the world's most reliable launcher and is safe to fly utilizing today's rigorous processes until a next generation system becomes available.

The cost savings reported by the Option 1 team did not consider management or contract infrastructure changes. These areas have the potential to offer additional cost reduction benefits; however, considerations such as these were beyond the scope of the Access to Space Study. Such studies may be appropriate and beneficial and, if so, should be undertaken by the Space Shuttle Program. It is recognized that the Space Shuttle Program has already emphasized operational efficiency improvements in its program.

Lastly, the Option 1 team recommended further studies of flyback, fully reusable liquid-fueled boosters for the Space Shuttle in order to increase safety and potentially reduce costs. These studies should be performed to further develop the possible benefits such a configuration might offer.

National Aerospace Plane

The selection of the rocket single-stage-to-orbit over the air-breathing single-stage vehicle by the Option 3 team was done for significant cost, risk, and schedule considerations. The air-breather option was determined to have more difficult technology and, therefore, would be more costly and take longer to develop.

However, air-breathing launchers potentially offer a number of unique mission capabilities in which they may have an advantage. These include launch into orbits with lower inclination than the latitude of the launch site, performing synergetic plane changes in order to over fly a given Earth location on successive orbits, and flexibility to perform single-orbit data collection missions. In addition, their technology is applicable to future hypersonic aircraft, both for civilian and defense applications.

Thus it was concluded that the National Aerospace Plane enabling technology program should continue independently of any decision to proceed with development of a nearer-term low-Earth orbit launch system.

Recommendations

The Access to Space Study makes a number of recommendations. These are summarized below.

1. Adopt the development of an advanced technology, fully reusable single-stage-to-orbit rocket vehicle as an Agency goal.
2. Pursue a technology maturation and demonstration program as a first phase of this activity.
   - The technologies developed should be aimed at a single-stage-to-orbit rocket using tripropellant propulsion and advanced structures and materials. This program would mature and demonstrate the technologies described in the Description of the Option Teams Analysis (Option 3) section and summarized in the Observations and Conclusions section.
   - A complementary experimental rocket vehicle technology demonstration flight program should be pursued in parallel with the technology development activity.
   - These activities should be paced so as to allow the earliest informed decision on development of a full-scale vehicle.
3. The technology, advanced development, and experimental vehicle programs should be coordinated with the Department of Defense.
4. The Space Shuttle and the current expendable launch vehicle programs should be continued. The most beneficial and cost-effective upgrades should be considered for incorporation into these vehicles until the new single-stage-to-orbit vehicle becomes available.
5. Although the focus of these recommendations is a technology maturation and demonstration program, additional studies should be conducted in parallel. They include system trade studies for the single-stage-to-orbit rocket vehicle configuration in order to guide the technology activities, and assessment of a flyback reusable liquid booster concept for the Space Shuttle.
6. The National Aero-Space Plane enabling technology program should be continued as a separate and distinct activity, as it contributes to future defense and civilian hypersonic aircraft programs, and it has potentially unique future mission applications.